Chapter 1
Introduction

This document presents the results of a cleaner technologies substitutes assessment (CTSA) of six technologies for performing the surface finishing function during the manufacture of printed wiring boards (PWBs). Surface finishing technologies deposit a coating on the outside surfaces of the PWB that provides a solderable surface for future assembly, while protecting the surface from exposure to the local environment. The technologies evaluated in the study are hot air solder leveling (HASL), electroless nickel/immersion gold (nickel/gold), electroless nickel/electroless palladium/immersion gold (nickel/palladium/gold), organic solderability preservative (OSP), immersion silver, and immersion tin.

For the purposes of this evaluation, the non-conveyorized HASL process is considered the baseline process against which alternative technologies and equipment configurations (i.e., non-conveyorized or conveyorized) are compared. This CTSA is the culmination of over two years of research by the U.S. Environmental Protection Agency (EPA) Design for the Environment (DfE) PWB Project and the University of Tennessee (UT) Center for Clean Products and Clean Technologies on the comparative risk, performance, cost, and natural resource requirements of the alternative technologies as compared to the baseline.

The DfE PWB Project is a voluntary, cooperative partnership among EPA, industry, public-interest groups, and other stakeholders to promote implementation of environmentally beneficial and economically feasible manufacturing technologies by PWB manufacturers. Project partners participated in the planning and execution of this CTSA by helping define the scope and direction of the CTSA, developing project workplans, donating time, materials, and their manufacturing facilities for project research, and reviewing technical information contained in this CTSA. Much of the process-specific information presented here was provided by chemical suppliers to the PWB industry, PWB manufacturers who responded to project information requests, and PWB manufacturers who volunteered their facilities for a performance demonstration of the baseline and alternative technologies.

Section 1.1 presents project background information, including summary descriptions of the EPA DfE Program and the DfE PWB Project. Section 1.2 is an overview of the PWB industry, including the types of PWBs produced, the market for PWBs, and the overall PWB manufacturing process. Section 1.3 summarizes the CTSA methodology, including a discussion of how technologies were selected for evaluation in the CTSA, the boundaries of the evaluation, issues evaluated, data sources, and project limitations. Section 1.4 describes the organization of the remainder of the CTSA document.

1.1 PROJECT BACKGROUND

The PWB is the connector between the semiconductors, computer chips, and other electronic components that form an electronic circuit. Therefore, PWBs are an irreplaceable part of many "high-tech" products in the electronics, defense, communications, and automotive industries. PWB manufacturing, however, typically generates a significant amount of hazardous waste, requires a substantial amount of water and energy, and uses chemicals that may pose environmental and health risks.

To address these issues, the PWB industry has been actively seeking to identify and evaluate cleaner technologies and pollution prevention opportunities. However, many PWB manufacturers do not have the resources or experience to independently develop the data needed to evaluate new technologies and redesign their processes. The DfE PWB Project was initiated to develop that data, by forming partnerships between the EPA DfE Program, the PWB industry, and other interested parties to facilitate the evaluation and implementation of alternative technologies that reduce health and environmental risks and production costs. The EPA DfE Program and the DfE PWB Project are discussed in more detail below.

1.1.1 EPA DfE Program

EPA's Office of Pollution Prevention and Toxics created the DfE Program in 1991. The Program uses EPA's expertise and leadership to facilitate information exchange and research on risk reduction and pollution prevention opportunities. DfE works on a voluntary basis with industry sectors to evaluate the risks, performance, costs, and resource requirements of alternative chemicals, processes, and technologies. Additional goals of the program include:

- changing general business practices to incorporate environmental concerns, and
- helping individual businesses undertake environmental design efforts through the application of specific tools and methods.

The DfE Program encourages voluntary environmental improvement through stakeholder partnerships. DfE partners include industry, trade associations, research institutions, environmental and public-interest groups, academia, and other government agencies. By involving representatives from each of these stakeholder groups, DfE projects gain the necessary expertise to perform the project's technical work and improve the quality, credibility, and utility of the project's results.

1.1.2 DfE PWB Project

The DfE PWB Project is a voluntary, cooperative partnership among EPA, industry, public-interest groups, and other stakeholders to promote implementation of environmentally beneficial and economically feasible manufacturing technologies by PWB manufacturers. In part, the project is an outgrowth of industry efforts to identify key cleaner technology needs in electronics manufacturing. The results of these industry studies are presented in two reports prepared by Microelectronics and Computer Technology Corporation (MCC), an industry research consortium: *Environmental Consciousness: A Strategic Competitiveness Issue for the Electronics and Computers Industry* (MCC, 1993) and *Electronics Industry Environmental Roadmap* (MCC, 1994).

The first study identified wet chemistry processes used in PWB fabrication as water- and energy-intensive processes that generate significant amounts of hazardous waste. The study concluded that effective collaboration among government, industry, academia, and the public is imperative to proactively address the needs of environmental technologies, policies, and practices (MCC, 1993). To follow-up, the industry embarked on a collaborative effort to develop an environmental roadmap for the electronics industry. The roadmap project involved more than 100 organizations, including EPA, the Department of Energy, the Advanced Research Projects Agency, and several trade associations. The PWB industry national trade association, the IPC-Association Connecting Electronics Industries (IPC), was instrumental in developing the information on PWBs through its Environmental, Health, and Safety Committee.

The highest priority need identified for PWB manufacturers was for more efficient use, regeneration, and recycling of hazardous wet chemistries. One proposed approach to meet this need was to eliminate formaldehyde from materials and chemical formulations by researching alternative chemical formulations. Another priority need was for industry to reduce water consumption and discharge, which can be accomplished by using wet chemistries that have reduced numbers of rinse steps. The electroless copper technologies for making holes conductive (MHC) use formaldehyde and consume large amounts of water.

The potential for improvement in these areas led EPA's DfE Program to forge working partnerships with IPC, individual PWB manufacturers and suppliers, research institutions such as MCC and UT's Center for Clean Products and Clean Technologies, and public-interest organizations, including the Silicon Valley Toxics Coalition. These partnerships resulted in the DfE PWB Project.

Since its inception in 1994, the goal of the DfE PWB Project has been the identification and evaluation of environmentally preferable alternative technologies for the PWB manufacturing industry. The project initially focused on the evaluation of alternative technologies for the MHC process. Seven MHC processes were evaluated for performance, cost, and their impact on human health and the environment. The project results are published in the *Printed Wiring Board Cleaner Technologies Substitutes Assessment: Making Holes Conductive* (U.S. EPA, 1998a).

The success of the MHC study led project partners to explore the possibility of a second project with the PWB manufacturing industry. Results of the environmental roadmap from 1994 identified a top priority need for PWB manufacturers as the need to minimize the impact of hazardous materials use in PWB fabrication. One proposed approach to meet this need was to eliminate or reduce lead solder use when possible by validating the quality of lead plating alternatives. Another priority need for the industry was to establish better supplier relationships to enhance the development and acceptance of environmentally preferable materials.

As a follow up to the environmental roadmap, the electronics industry embarked on a study of industry technology trends, the results of which were published as *The National Technology Roadmap for Electronic Interconnections* (IPC, 1996). The roadmap detailed trends in PWB manufacturing and assembly technologies, and forecasted the technology needs for the industry over the immediate future. The study concluded that major efforts are needed to overcome the reluctance to trying new and innovative ideas, citing the environmental pressure to reduce hazardous waste and the use of lead. The results also cited the development of non-tin/lead metallic or organic coatings to retain solderability characteristics as an industry need over the near term.

Recognizing the importance of reducing lead consumption in the PWB industry, and building on the strong partnerships established during the previous work, the PWB surface finishing project was begun in 1997 to evaluate alternative surface finishing technologies to HASL. This CTSA is a culmination of this effort. During this time, the project has also:

- Prepared several additional case studies of pollution prevention opportunities (U.S. EPA, 1997a; U.S. EPA, 1997b; U.S. EPA, 1997c; U.S. EPA, 1999).
- Prepared an implementation guide for PWB manufacturers interested in switching from HASL to an alternative surface finishing technology (U.S. EPA, 2000).
- Identified, evaluated, and disseminated information on viable pollution prevention opportunities for the PWB industry through an updated review of a pollution prevention and control practices industry study (U.S. EPA, 1998b).

Further information about the project, along with web-based versions of all the documents listed above and other previous project work, can be obtained by visiting the Design for the Environment Program website, located at www.epa.gov/dfe/pwb.

1.2 OVERVIEW OF PWB INDUSTRY

1.2.1 Types of Printed Wiring Boards

PWBs may be categorized in several ways, either by the number of layers or by the type of substrate. The number of circuit layers present on a single PWB give an indication of the overall complexity of the PWB. The most common categories are multi-layer, double-sided, and single-sided PWBs. Multi-layer PWBs contain more than two layers of circuitry, with at least one layer imbedded in the substrate beneath the surface of the board. Multi-layer boards may consist of 20 or more interconnected layers, but four, six, and eight layer boards are more common. Double-sided boards have circuitry on both sides of a board, resulting in two interconnected layers, while single-sided PWBs have only one layer of circuitry. Double-sided and single-sided PWBs are generally easier to produce than multi-layer boards (U.S. EPA, 1995).

PWB substrates, or base material types, fall into three basic categories: rigid PWBs, flexible circuits, and rigid-flex combinations. Rigid multi-layer PWBs dominate the domestic production of all PWBs (see Section 1.2.2, below) and are the focus of this CTSA.

Rigid PWBs typically are constructed of glass-reinforced epoxy-resin systems that produce a board less than 0.1" thick. The most common rigid PWB thickness is 0.062", but there is a trend toward thinner PWBs. Flexible circuits (also called flex circuits) are manufactured on polyamide and polyester substrates that remain flexible at finished thicknesses. Ribbon cables are common flexible circuits. Rigid-flex PWBs are essentially combinations or assemblies of rigid and flexible PWBs. They may consist of one or more rigid PWBs that have one or more flexible circuits laminated to them during the manufacturing process. Three-dimensional circuit assemblies can be created with rigid-flex combinations (U.S. EPA, 1995).

1.2.2 Industry Profile

The total world market for PWBs is about $31.4 billion, with U.S. production accounting for about one quarter of the total (Wehrspann, 1999a). Although the United States and Japan are the leading suppliers of PWBs, Hong Kong, Singapore, Taiwan, and Korea also have captured a significant share of the world market. The U.S.-dominated world market for PWBs eroded from 1980 to 1990, but has come back slightly in recent years. The market share of the countries with the largest PWB production is shown in Figure 1-1.

IPC estimates that the U.S. market for PWBs in 1998 totaled approximately $8.6 billion for both rigid and flex PWBs. U.S. imports of PWBs were estimated to be approximately $500 to $600 million annually, the majority of which come from Taiwan, Japan, Hong Kong, Korea, and Thailand (Wehrspann, 1999b). The value of U.S. PWB exports reported for 1998 were approximately $100 million, which represents two to three percent of total U.S. PWB production (Wehrspann, 1999b).

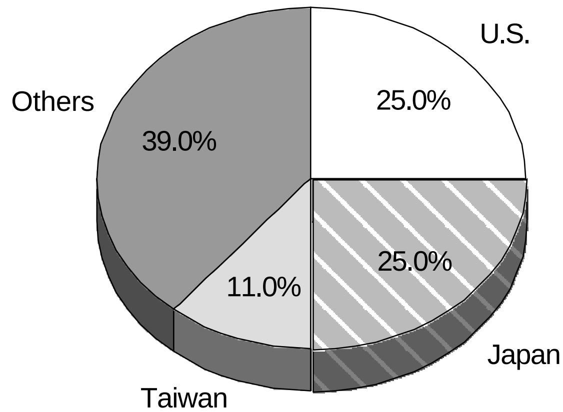

Figure 1-1. PWBs Produced for World Market in 1998 (IPC)

The United States had 652 independent PWB manufacturing plants in 1999 (Abrams, 2000). California, Minnesota, Texas, Illinois, Massachusetts, and Arizona have the highest number of PWB manufacturing plants, but there are PWB manufacturing facilities in virtually all 50 states and territories. More than 75 percent of U.S.-made PWBs are produced by independent shops (U.S. EPA, 1995).

About 80 percent of independent PWB manufacturers are small- to medium-sized businesses with annual sales under $10 million, but these shops only account for 20 to 25 percent of total U.S. sales. Conversely, about five percent of PWB manufacturers are larger independent shops with annual sales over $20 million, but these shops account for about 70 percent of total U.S. sales (Wehrspann, 1999b). Recent industry trends have seen the purchase of many smaller companies by larger corporations with much larger annual sales.

Overall U.S. production accounted for 1.4 billion PWBs produced in 1998. While demand for multi-layer PWBs continues to grow, both single- and double-sided PWBs are still produced in greater numbers. The market for multi-layer boards was about $7.9 billion in 1998 (Wehrspann, 1999b), up from approximately $700 million in 1980 (U.S. EPA, 1995). A breakdown of U.S. production by the type of PWB is shown in Figure 1-2.

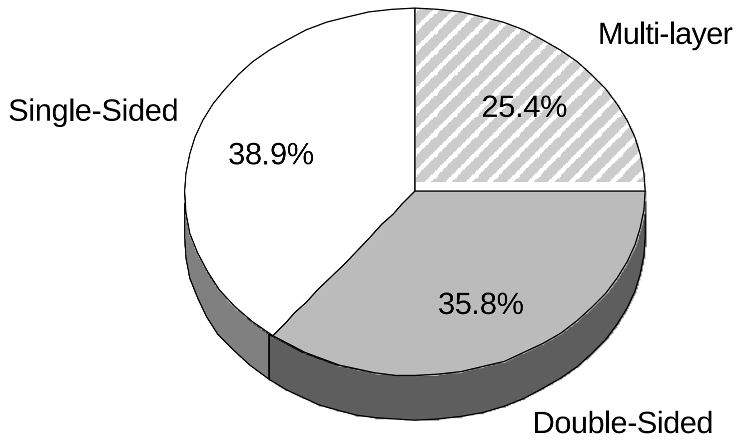

Figure 1-2. Number of PWBs Produced by U.S. Manufacturers in 1998 (IPC)

The PWB industry directly employs about 75,000 people, with about 68 percent of employment in production jobs. This is the highest ratio of production jobs for U.S. electronics manufacturing (U.S. EPA, 1995). Additional jobs related to the industry are generated by PWB material and equipment suppliers and the OEMs that produce PWBs for internal use. Further information about the industry may be found in *Printed Wiring Board Industry and Use Cluster Profile* (U.S. EPA, 1995) or from contacting the industry trade association, IPC.

1.2.3 Overview of Rigid Multi-Layer PWB Manufacturing

Multi-layer boards consist of alternating layers of conductor and insulating material bonded together. Individual circuitry inner-layers are created and then assembled under high temperature into a solid board. Holes are drilled through the boards, and then plated to provide layer-to-layer connection on multi-layered circuits. The outside layers are imaged, plated, and then etched to create the circuitry traces on the outside surfaces of the PWB. A solder mask is then applied to the board prior to applying the final surface finish.

Application of the surface finish is the last major step in the PWB manufacturing process. The function of the surface finish is to provide a clean, solderable surface for subsequent assembly, while also protecting the surface from degradation or contamination from environmental factors, such as water, temperature, and oil from handling. The surface finishing technologies evaluated in this report all deposit this solderable layer, or coating. Traditionally, the surface finish has been tin-lead solder, applied using the HASL technology.

1.3 CTSA METHODOLOGY

The CTSA *methodology* is a means of systematically evaluating and comparing human health and environmental risk, competitiveness (i.e., performance, cost, etc.), and resource requirements of traditional and alternative chemicals, manufacturing methods, and technologies in a particular use cluster. A use cluster is a set of chemical products, technologies, or processes that can substitute for one another to perform a particular function. A CTSA *document* is the repository for the technical information developed by a DfE project on a use cluster. Thus, surface finishing technologies comprise the use cluster that is the focus of this CTSA.

The overall CTSA methodology used in this assessment was developed by the EPA DfE Program, the UT Center for Clean Products and Clean Technologies, and other partners in voluntary, industry-specific pilot projects. The publication, *Cleaner Technologies Substitutes Assessment: A Methodology & Resource Guide* (Kincaid et al., 1996) presents the CTSA methodology in detail. This section summarizes how the various technologies were selected for evaluation in the CTSA, identifies issues evaluated and data sources, and describes the project limitations. Chapters 2 through 6, and appendices, describe in detail the methods used to evaluate the technologies.

1.3.1 Identification of Alternatives and Selection of Project Baseline

Once the use cluster for the CTSA was chosen, industry representatives identified technologies that may be used to accomplish the surface finishing function. Initially, eight technology categories were identified, including six inorganic metal-based technologies, and two organic-based coatings. These include:

- Inorganic: HASL, nickel/gold, nickel/palladium/gold, immersion silver, immersion palladium, and immersion tin.
- Organic: OSP (benzotriazole-based), and OSP (substituted immidizole-based).

Suppliers were contacted by EPA and asked to submit their product lines in these technology categories for evaluation in the CTSA. Criteria for including a technology in the CTSA were the following:

- it is an existing or emerging technology; and
- there are equipment and facilities available to demonstrate its performance.

In addition, suppliers were required to provide information about their technologies, including chemical product formulation data, process schematics, process characteristics and constraints (e.g., cycle time, limitations for the acid copper plating process, substrate and drilling compatibilities, aspect ratio capacity, range of hole sizes), bath replacement criteria, and cost information.

Product lines were submitted, along with confidential process formulation data, for all of the technologies except the benzotriazole-based OSP technology. After further review, it was determined that the immersion palladium technology could not be demonstrated sufficiently under production conditions, preventing the evaluation of the technology's performance and cost of operation. As a result, only a process description of the immersion palladium technology is presented in this CTSA. Thus, seven categories of technologies were carried forward for further evaluation in the CTSA.

The HASL technology was selected as the project baseline for the following reasons:

- It is generally regarded to be the industry standard and holds the vast majority of the market for surface finishing technologies.
- Possible risk concerns associated with lead exposure, the large amount of solid waste generated by the HASL process, and the fact that the solder finish has become technologically limiting with regard to current design and assembly practices have prompted many PWB manufacturers to independently seek alternatives to HASL.

As with other surface finishing technologies, the HASL process can be operated using vertical, immersion-type, non-conveyorized equipment or horizontal, conveyorized equipment. Conveyorized surface finishing equipment is usually more efficient than non-conveyorized equipment, but requires a substantial capital investment. Most facilities in the United States still use a non-conveyorized HASL process to perform the surface finishing function. Therefore, the baseline technology was further defined to only include non-conveyorized HASL processes. Conveyorized HASL processes, and both non-conveyorized and conveyorized equipment configurations of the other technology categories, are all considered to be alternatives to non-conveyorized HASL.

1.3.2 Boundaries of the Evaluation

For the purposes of the environmental evaluation (i.e., human health and ecological hazards, exposure, risk, and resource consumption), the boundaries of this evaluation can be defined in terms of the overall life cycle of the surface finishing products and in terms of the PWB manufacturing process. The life cycle of a product or process encompasses extraction and processing of raw materials, manufacturing, transportation and distribution, use/re-use/maintenance, recycling, and final disposal. As discussed in Section 1.2.3, rigid, multi-layer PWB manufacturing encompasses a number of process steps, of which the surface finishing process is the last one.

The activities evaluated in this study are primarily the use of surface finishing chemicals at PWB facilities and the release or disposal of surface finishing chemicals from PWB facilities. However, in addition to evaluating the energy consumed during surface finishing line operation, the analysis of energy impacts (Section 5.2) also discusses the pollutants generated from producing the energy to operate the surface finishing line, as well as energy consumed in other life-cycle stages, such as the manufacture of chemical ingredients. In addition, information is presented on the type and quantity of wastewater generated by the surface finishing process line, and the risk to the environment resulting from the discharge of the wastewater to nearby surface water (Section 3.4). Finally, while information is presented on the generation and disposal of solid waste from surface finishing technologies, there was insufficient information to characterize the risk from these environmental releases. This is discussed in more detail in Section 3.1, Source Release Assessment.

In terms of the PWB manufacturing process, this analysis focused entirely on the surface finishing process, defined as beginning with a panel that has had solder mask applied, and ending after a surface finish has been applied to the connecting surfaces of the PWB and the board has been cleaned of any residual process chemistry. In cases where no solder mask is applied, the use cluster would begin after the stripping of the etch resist from the outside board surfaces.

The narrow focus on surface finishing technologies yields some benefits to the evaluation, but it also has some drawbacks. Benefits include the ability to collect extremely detailed information on the relative risk, performance, cost, and resources requirements of the baseline technology and alternatives. This information provides a more complete assessment of the technologies than has previously been available and would not be possible if every step in the PWB manufacturing process was evaluated. Drawbacks from such focused evaluations include the inability to identify all of the plant-wide benefits, costs, or pollution prevention opportunities that could occur when implementing an alternative to the baseline HASL technology. However, given the variability in workplace practices and operating procedures at PWB facilities, these other benefits and opportunities are expected to vary substantially among facilities and would be difficult to assess in a comparative evaluation such as a CTSA. Individual PWB manufacturers are urged to assess their overall operations for pollution prevention opportunities when implementing an alternative technology.

1.3.3 Issues Evaluated

The CTSA evaluated a number of issues related to the risk, competitiveness, and resource requirements of surface finishing technologies. These include the following:

- Risk: occupational health risks, public health risks, ecological hazards, and process safety concerns.
- Competitiveness: technology performance, cost, and regulatory status.
- Conservation: energy and natural resource use.

Occupational and public health risk information is for chronic exposure to long-term, day-to-day exposure and releases from a PWB facility rather than short-term, acute exposures to high levels of hazardous chemicals as could occur with a fire, spill, or other periodic release. Risk information is based on exposures estimated for a model facility, rather than exposures estimated for a specific facility. Ecological risks are also evaluated for aquatic organisms that could be exposed to surface finishing chemicals through wastewater discharges. Process safety concerns are summarized from material safety data sheets (MSDSs) for the technologies and process operating conditions.

Technology performance is based on a snapshot of the performance of the surface finishing technologies at volunteer test sites in the United States. Panels were electrically prescreened, followed by electrical stress testing, accelerated aging, and mechanical testing, in order to distinguish robustness of the applied surface finishes. Comparative costs of the surface finishing technologies were estimated with a hybrid cost model that combines traditional costs with simulation modeling and activity-based costs. Costs are presented in terms of dollars per surface square feet (ssf) of PWB produced.

Federal environmental regulatory information is presented for the chemicals in the surface finishing technologies. This information is intended to provide an indication of the regulatory requirements associated with a technology, but not to serve as regulatory guidance.

Quantitative resource consumption data are presented for the comparative rates of metal, energy, and water use by the surface finishing technologies. The consumption of other resources, such as process and treatment chemicals, are qualitatively assessed.

1.3.4 Primary Data Sources

Much of the process-specific information presented in this CTSA was provided by chemical suppliers to the PWB industry, PWB manufacturers who responded to project information requests, and PWB manufacturers who volunteered their facilities for a performance demonstration of the baseline and alternative technologies. The types of information provided by chemical suppliers and PWB manufacturers are summarized below.

Chemical Suppliers

The project was open to all interested chemical suppliers, provided that they agreed to disclose confidential chemical formulation data for use in this evaluation, and that their technologies met the criteria described in Section 1.3.1. Table 1-1 lists the suppliers who participated in the CTSA and the categories of surface finishing technologies they submitted for evaluation. It should be noted that this is not a comprehensive list of surface finishing technology suppliers. EPA made every effort to publicize the project through trade associations, PWB manufacturers, industry conferences and other means, but some suppliers did not learn of the project until it was too late to submit technologies for evaluation, or chose not to participate.

Table 1-1. Surface Finishing Technologies Submitted by Chemical Suppliers

Chemical Supplier	Surface Finishing Technology				
	Nickel/Gold	Nickel/Palladium/Gold	OSP	Immersion Silver	Immersion Tin
Polyclad Technologies-Enthone				X	X
Electrochemicals, Inc.			X		
Florida CirTech, Inc.					X
MacDermid, Inc.	X	X	X		
Technic, Inc.	X				

A supplier for HASL is not shown in Table 1-1 because the HASL technology is not sold as a product line by a supplier. Instead, it consists a series of chemical cleaning and flux steps, followed by HASL equipment, which mechanically applies the solder to PWB surface. The board is then cleaned using a water rinse cleaning system. The chemical baths preceding the HASL equipment are not designed specifically for use with the HASL process, and are similar to those used by other surface finishing technologies. Chemical data from cleaning baths in other processes were substituted for this analysis. HASL equipment is commercially available from a number of suppliers.

Each of the chemical suppliers provided the following: MSDSs for the chemical products in their surface finishing technology lines; Product Data Sheets, which are technical specifications prepared by suppliers for PWB manufacturers that describe how to mix and maintain the chemicals baths; and complete product formulation data. Suppliers were also asked to complete a Supplier Data Sheet, designed for the project, which included information on chemical cost, equipment cost, water consumption rates, product constraints, and the locations of test sites for the Performance Demonstration. Appendix A contains a copy of the Supplier Data Sheet.

PWB Manufacturers

PWB manufacturers were asked to participate in a study of workplace practices. The PWB Workplace Practices Questionnaire requested detailed information on facility size, process characteristics, chemical consumption, worker activities related to chemical exposure, water consumption, and wastewater discharges. The questionnaire was distributed by IPC to PWB manufacturers. PWB manufacturers returned the completed questionnaires to IPC, which removed all facility identification and assigned a code to the questionnaires prior to forwarding them to UT's Center for Clean Products and Clean Technologies. In this manner, PWB manufacturers were guaranteed confidentiality of data.

For the Performance Demonstration project the PWB Workplace Practices Questionnaire was modified and divided into two parts: a Facility Background Information Sheet and an Observer Data Sheet. The Facility Background Information Sheet was sent to PWB facilities participating in the Performance Demonstration prior to their surface finishing technology test date. It requested detailed information on facility and process characteristics, chemical consumption, worker activities related to chemical exposure, and water consumption. The Observer Data Sheet was used by an on-site observer to collect data during the Performance Demonstration. In addition to ensuring that the performance test was conducted according to the agreed-upon test protocol, the on-site observer collected measured data, such as bath temperature and process line dimensions, and difficult to collect data, such as equipment loading rates and energy usage. The observer also checked survey data collected on the Facility Background Information Sheet for accuracy. Appendix A contains copies of the PWB Workplace Practices Questionnaire, the Facility Background Information Sheet, and the Observer Data Sheet forms.

Table 1-2 lists the number of PWB manufacturing facilities that completed the PWB Workplace Practices Questionnaire by type of surface finishing process, excluding responses with poor or incomplete data. Of the 54 responses to the questionnaire, 16 were Performance Demonstration test sites.

Table 1-2. Responses to the PWB Workplace Practices Questionnaire

Surface Finishing Technology	No. of Responses	Surface Finishing Technology	No. of Responses
HASL	29	OSP	9
Nickel/Gold	8	Immersion Silver	2
Nickel/Palladium/Gold	1	Immersion Tin	5

Information from the pollution prevention and control technologies survey conducted by the DfE PWB Project was also used in the CTSA. These data are described in detail in the EPA publication, *Printed Wiring Board Pollution Prevention and Control Technology: Analysis of Updated Survey Results* (U.S. EPA, 1998b).

1.3.5 Project Limitations

There are a number of limitations to the project, both because of the predefined scope of the project and data limitations inherent to the characterization techniques. Some of the limitations related to the risk, competitiveness, and conservation components of the CTSA are summarized below. More detailed information on limitations and uncertainties for a particular portion of the assessment is given in the applicable sections of this document. A limitation common to all components of the assessment is that the surface finishing chemical products assessed in this report were voluntarily submitted by participating suppliers and may not represent the entire surface finishing technology market. For example, the immersion palladium and benzotriazole-based OSP technologies were not evaluated in the CTSA. Alternatives that are evaluated were submitted by at least one supplier, but not necessarily by every supplier who offers that surface finishing technology.

Risk

The risk characterization is a screening level assessment of multiple chemicals used in surface finishing technologies. The focus of the risk characterization is on chronic (long-term) exposure to chemicals that may cause cancer or other toxic effects, rather than on acute toxicity from brief exposures to chemicals. The exposure assessment and risk characterization use a "model facility" approach, with the goal of comparing the exposures and health risks of the surface finishing process alternatives to the baseline HASL technology. Characteristics of the model facility were aggregated from questionnaire data, site visits, and other sources, and are based on the assumption of manufacturing 260,000 ssf per year. This approach does not result in an absolute estimate or measurement of risk.

In addition, the exposure and risk estimates reflect only a portion of the potential exposures within a PWB manufacturing facility. Many of the chemicals found in surface finishing technologies may also be present in other process steps of PWB manufacturing, and other risk concerns for human health and the environment may occur from other process steps. Incremental reduction of exposures to chemicals of concern from a surface finishing process, however, will reduce cumulative exposures from all sources in a PWB facility, provided that increased production does not increase plant-wide pollution.

Finally, information presented in this CTSA is based on publicly-available chemistry data submitted by each of the participating suppliers, as well as proprietary data submitted by the suppliers. Risk information for proprietary ingredients is included in this CTSA, but chemical identities and chemical properties are not listed.

Competitiveness

The Performance Demonstration was designed to provide a snapshot of the performance of different surface finishing technologies. The test methods used to evaluate performance were intended to indicate characteristics of a technology's performance, not to define parameters of performance or to substitute for thorough on-site testing. Because the test sites were not chosen randomly, the sample may not be representative of all PWB manufacturing facilities in the United States (although there is no specific reason to believe they are not representative).

The cost analysis presents comparative costs of using a surface finishing technology in a model facility to produce 260,000 ssf of PWBs. As with the risk characterization, this approach results in a comparative evaluation of cost, not an absolute evaluation or determination. The cost analysis focuses on private costs that would be incurred by facilities implementing a technology. It does not evaluate community benefits or costs, such as the effects on jobs from implementing a more efficient surface finishing technology. However, the Social Benefits/Costs Assessment (see Section 7.2) qualitatively evaluates some of these external (i.e., external to the decision-maker at a PWB facility) benefits and costs.

The regulatory information contained in the CTSA may be useful in evaluating the benefits of moving away from processes containing chemicals that trigger compliance issues. However, this document is not intended to provide compliance assistance. If the reader has questions regarding compliance concerns, they should contact their federal, state, or local authorities.

Conservation

The analysis of energy and water consumption is also a comparative analysis, rather than an absolute evaluation or measurement. Similar to the risk and cost analyses, consumption rates were estimated based on using a surface finishing technology in a model facility to produce 260,000 ssf of PWB.

1.4 ORGANIZATION OF THIS REPORT

This CTSA is organized into two volumes: Volume I summarizes the methods and results of the CTSA; Volume II consists of appendices, including detailed chemical properties and methodology information.

Volume I is organized as follows:

- Chapter 2 gives a detailed profile of the surface finishing use cluster, including process descriptions of the surface finishing technologies evaluated in the CTSA and the estimated concentrations of chemicals present in surface finishing chemical baths.
- Chapter 3 presents risk information, beginning with an assessment of the sources, nature, and quantity of selected environmental releases from surface finishing processes (Section 3.1); followed by an assessment of potential exposure to surface finishing chemicals (Section 3.2) and the potential human health and ecological hazards of surface finishing chemicals (Section 3.3). Section 3.4 presents quantitative risk characterization results, while Section 3.5 discusses process safety concerns.
- Chapter 4 presents competitiveness information, including performance demonstration results (Section 4.1), cost analysis results (Section 4.2), and regulatory information (Section 4.3).
- Chapter 5 presents conservation information, including an analysis of water and other resource consumption rates (Section 5.1) and energy impacts (Section 5.2).
- Chapter 6 describes additional pollution prevention and control technology opportunities (Sections 6.1 and 6.2, respectively).
- Chapter 7 organizes data collected or developed throughout the CTSA in a manner to facilitate decision-making. Section 7.1 presents a summary of risk, competitiveness, and conservation data. Section 7.2 assesses the social benefits and costs of implementing an alternative as compared to the baseline. Section 7.3 provides summary profiles for the baseline and each of the surface finishing alternatives.

REFERENCES

Abrams, Fern. 2000. IPC-Association Connecting Electronics Industries). Personal communication with Jack Geibig, UT Center for Clean Products and Clean Technologies. December.

IPC (IPC-Association Connecting Electronics Industries). 1996. *The National Technology Roadmap for Electronic Interconnections*.

Kincaid, Lori E., Jed Meline and Gary Davis. 1996. *Cleaner Technologies Substitutes Assessment: A Methodology & Resource Guide.* EPA Office of Pollution Prevention and Toxics. Washington, D.C. EPA 744-R-95-002. December.

MCC (Microelectronics and Computer Technology Corporation). 1993. *Environmental Consciousness: A Strategic Competitiveness Issue for the Electronics and Computer Industry*. March.

MCC (Microelectronics and Computer Technology Corporation). 1994. *Electronics Industry Environmental Roadmap*. December.

U.S. EPA (Environmental Protection Agency). 1995. *Printed Wiring board Industry and Use Cluster Profile.* EPA Office of Pollution Prevention and Toxics. Washington, D.C. EPA/744-R-95-005. September.

U.S. EPA (Environmental Protection Agency). 1997a. "Printed Wiring Board Case Study 6: Pollution Prevention Beyond Regulated Materials." EPA Office of Pollution Prevention and Toxics. Washington, D.C. EPA 744-F-97-006. May.

U.S. EPA (Environmental Protection Agency). 1997b. "Printed Wiring Board Case Study 7: Identifying Objectives for your Environmental Management System." EPA Office of Pollution Prevention and Toxics. Washington, D.C. EPA 744-F-97-009. July.

U.S. EPA (Environmental Protection Agency). 1997c. "Printed Wiring Board Case Study 8: Building an EMS, H-R Industries Experience." EPA Office of Pollution Prevention and Toxics. Washington, D.C. EPA 744-F-97-010. December.

U.S. EPA (Environmental Protection Agency). 1998a. *Printed Wiring Board Cleaner Technologies Substitutes Assessment: Making Holes Conductive.* Design for the Environment Printed Wiring Board Project. EPA Office of Pollution Prevention and Toxics. Washington, D.C. EPA/744-R-98-004a and EPA/744-R-98-004b. August.

U.S. EPA (Environmental Protection Agency). 1998b. *Printed Wiring Board Pollution Prevention and Control Technology: Analysis of Updated Survey Results.* Design for the Environment Printed Wiring Board Project. EPA Office of Pollution Prevention and Toxics. Washington, D.C. EPA 744-R-98-003. August.

U.S. EPA (Environmental Protection Agency). 1999. "Printed Wiring Board Case Study 9: Flexible Simulation Modeling of PWB Costs." EPA Office of Pollution Prevention and Toxics. Washington, D.C. EPA 744-F-99-004. May.

U.S. EPA (Environmental Protection Agency). 2000. *Implementing Cleaner Printed Wiring Board Technologies: Surface Finishes*. EPA Office of Pollution Prevention and Toxics. Washington, D.C. EPA 744-R-00-002. March.

Wehrspann, Carla. 1999a. IPC-Association Connecting Electronics Industries. Personal communication with Jeng Hon Su, University of Tennessee Center for Clean Products and Clean Technologies. July.

Wehrspann, Carla. 1999b. IPC-Association Connecting Electronics Industries. Personal communication with Jack Geibig, University of Tennessee Center for Clean Products and Clean Technologies. June.